THE FRANCO-GERMAN TIGER PROGRAM CURRENT MANUFACTURE AND TEST SITUATION FOR STRUCTURAL AND MECHANICAL COMPONENTS

Wolfgang JONDA
MBB
Ottobrünn - GERMANY

Jean-Paul LIBEER
Auguste DESMONCEAUX
AEROSPATIALE
Marignane - FRANCE

ABSTRACT :

Following the official decision to launch the development at the end of 1987 and, particularly since the signature of the MDC (Main Development Contract) at the end of 1989, the «TIGER» Program has entered an extremely busy and concrete phase.

The aim is to develop and qualify from now until 1996/98 the HAC/PAH2 and HAP weapon systems. These weapon systems will be integrated in a carrier, the basic helicopter, that will have to demonstrate a high level of performance and reliability in order to optimize the use and performance of the weapon systems.

The subject of this paper is to present the current manufacture and test situation of the basic helicopter main components. General information is also given on the technology selected for these components and the test facilities.

Now, every basic aircraft component has been studied, designed and manufactured and numerous evaluation tests are in progress. The rotors and transmissions were pre-tested on their respective rigs : whirl tower, back to back rig, tail rotor rig, fatigue test rig...

The whole dynamic assembly (rotors, gear boxes, transmission shafts and flight controls) are ready to run on the «Iron Bird».

The first prototype (PT1) final assembly has almost been completed. The following steps will be the check and ground tests of each sub-system, the flight test installation and every actions leading to the first flight which has been planned for april 1991.

1. Introduction

Fig. 1 : TIGER FULL SCALE MOCK-UP IN ANTI-TANK CONFIGURATION

The discussions to define and launch the development of the HAC/PAH2/HAP helicopter lasted a long time, more than 10 years in all, and after an initial development contract (IDC) covering the work done in 1988 and 1989, the main development contract (MDC) was signed on 30.11.89 between the two governments and industries.

The French and German governments were represented by the D.F.H.B. (Deutsch Französisches Hubschrauber Büro) and the industry by EUROCOPTER, an AEROSPATIALE - MBB CONSORTIUM.

This main contract covers the development of a basic aircraft and the associated weapon systems up to their qualification in 1996/1998 ; it includes flight testing five prototypes in various configurations, as well as developing the weapon system logistics and the related drawings for series production.

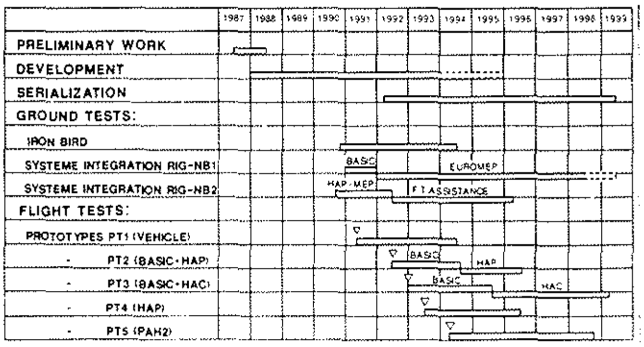

Fig 2 : DEVELOPMENT SCHEDULE

The three versions to be developed are :

- HAP, the French combat support version designed for ground protection with rockets and a gun as well as air-to-air combat with Mistral missile and a gun.

- HAC and PAH2, respectively the French and German anti-tank versions to be equipped with Hot and AC3G anti-tank missiles as well as Mistral or Stinger air-to-air missiles.

The air-to-ground and air-to-air missions have to be performed by day or night and in adverse environmental conditions.

The basic helicopter has been designed in accordance with general safety, reliability, maintainability and comfort requirements comparable to those of modern civil helicopters but it also had to meet numerous military requirements such as :

- being capable to accomodate the different weapon systems i.e. roof or mast mounted sight, gun, outside weapons, computers etc. in optimum installation conditions

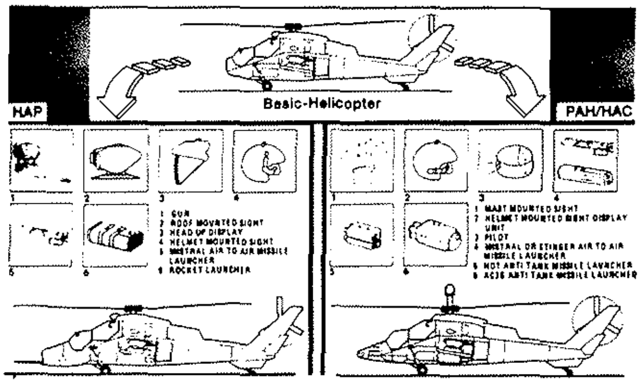

Fig. 3 : CONCEPT PHILOSOPHY

- having the exceptional performance, the power reserve and the stability/manoeuvrability qualities necessary to become an excellent firing platform

- meeting the survivability requirements covered in the following specifications :

  . detectability (visual, noise, radar, I.R.)
  . vulnerability to impacts of various calibers
  . crash resistance
  . NBC threat protection

Every basic aircraft component has now been studied, designed and manufactured. The dynamic components i.e. rotors, transmissions and flight controls have been assembled together on the «Iron Bird». The first prototype assembly is now in its final phase before the sub-systems' ground tests.

The intention of this paper is to give an overview of the basic A/C development situation via a presentation of the current manufacture and test situation of the vehicle's main components:

- airframe
- dynamic assembly
- fligh controls and hydraulic system
- engines and associated sub-systems.

General information is also given on the technology selected for each item and the test facilities.

2. Airframe

2.1 Design

The Tiger will be the first all composite helicopter coming into service in 1996. The results from several pre-demonstrator programmes conducted at MBB as well as AEROSPATIALE have been the basis to design the primary and secondary structure of this aircraft. As far as possible, carbon composites with T 300 fibre material have been chosen to achieve a unique design with a minimum number of materials, a most cost effective serial production solution. Only a few exceptions were accepted for the first prototype : titanium in the designated fire zones, Kevlar skins for a high frequency transparent area in the tailboom, and Al sandwich for the cockpit floor.

Based on the knowledge of the pre-demonstrator programmes single block or sandwich panel have been used to obtain an optimized low weight design for the primary structure.

Depending on the environmental conditions for which the components are developed, epoxy prepregs cured at 120° or 180° C were used.

The airframe is divided in 3 main sections, the forward section including the tandem cockpit, the center section supporting the drive and fuel system and the rear section comprising the empennage, which allows to manufacture optimum size single components, special preassemblies, in parallel with a well balanced workshare necessary in cooperation programme.

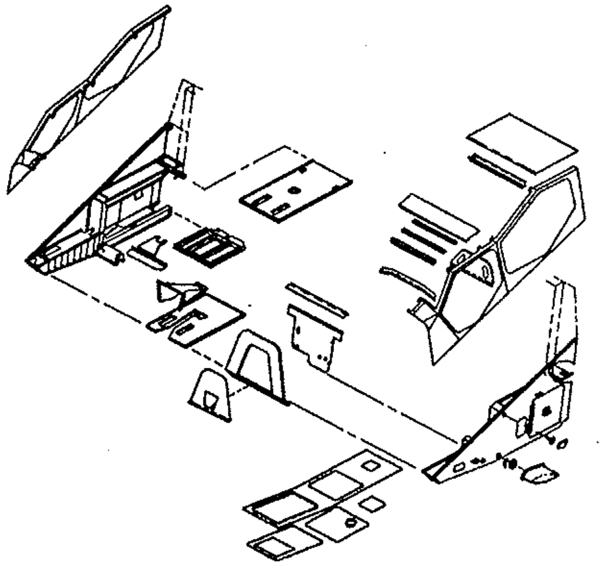

Fig. 4 : TIGER COMPOSITE FUSELAGE - FORWARD SECTION

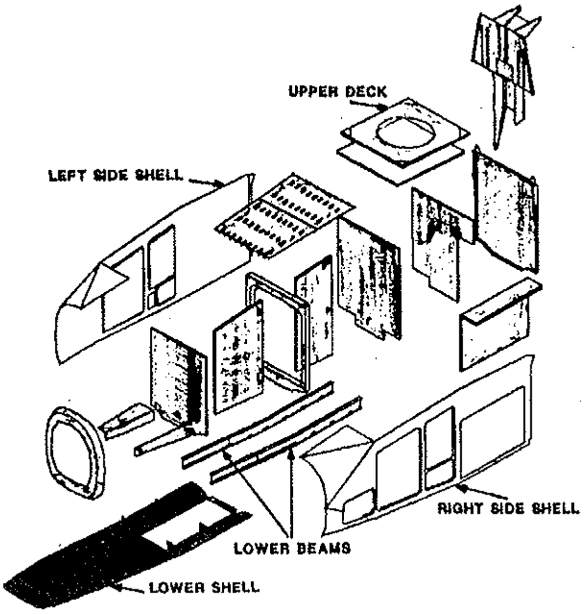

Fig. 5 : TIGER COMPOSITE FUSELAGE - CENTRAL SECTION

Each of these main sections is built up from several single components which are themselves designed for optimum size. The 3 pictures present exploded views of the 3 sections.
The components are interconnected with blind rivets, screws or adhesive films with blind rivets, depending on the structure zone.

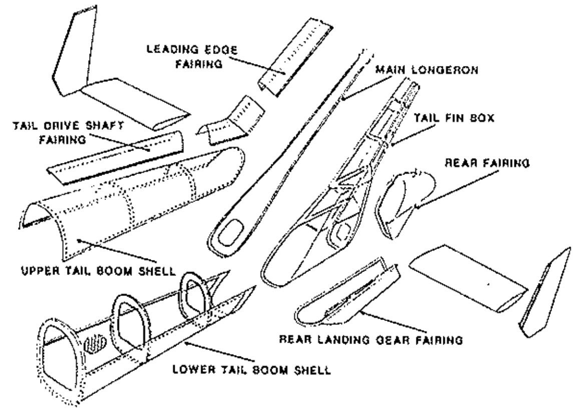

Fig. 6 : TIGER COMPOSITE FUSELAGE - AFT SECTION

The main sections, front and center fuselage are interconnected with rivetted splices ; the center and rear fuselage are interconnected with screws to allow for easy separation.

Since composites are used for the main structure, special attention must be paid to crash, EMI and lightning protection.

2.2 Manufacturing

Based on the composite experience of both companies, the prototypes will be manufactured with metal tools, using steel or INVAR to minimize manufacturing problems due to thermal expansion. Both 120° and 180° C curing cycles in an autoclave were selected, according to the in-service environmental conditions for the components.

Although the prototype's single components are built up with manual lay up technics, some partly automatic manufacturing procedures will be used in series production to obtain a low cost but high quality product.

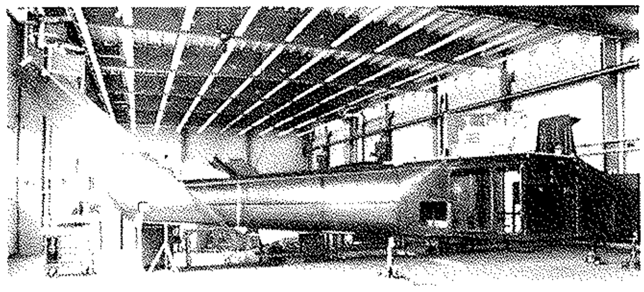

Fig. 7 : PT1 AIRFRAME ASSEMBLY

2.3 Tests

Various tests are necessary to show compliance with the requirements applicable to this aircarft. Amongst the most significant are, as mentioned before,

Strength
EMI/Lightning
Crash

*** Strength**

From the beginning, the airframe structure was designed to be fail-safe to avoid single, load carrying components. This allows reducing the number of necessary structural tests to a minimum. Generally, 4 different test validation procedures are undertaken for strength validation as follows.

1. Coupon Tests : materials selected
2. Structural Elements : joints, crippling sandwich tests
3. Subcomponents and Components : critical areas or representative components.
4. Full Scale Tests :experimental substantiation of some critical load cases and verification of finite element model (RT/A) in order to use the FE-Model for the substantiation of supplemental load cases.

Some of these tests will be performed prior to the 1st flight ; these tests are summarized in the following picture.

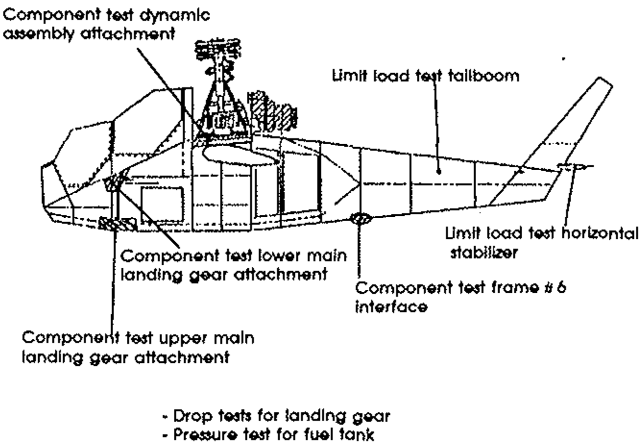

Fig. 8 : TEST PRIOR TO 1st FLIGHT

*** EMI/Lightning**

Using composites involves some special tests. Immediately beginning the detail design, a test box with several features was built to analyse, evaluate and select different solutions for surface protection and sealing of the electronic compartments. An adequate design for these aircraft areas could be established with these early test results.

Special attention was given to protect the equipment against high energy electromagnetic threats. As far as necessary, the composite structure is covered with a copper/bronze grid. In addition, the equipment bays include other provisions. Massive copper strips, together with the EMI precautions, create the lightning protection system for the airframe.

*** Crash**

The airframe stucture is designed to withstand the required crash speeds with a special high ernergy absorption underfloor structure. In certain areas, so called sine wave elements, which have proven their applicability in several tests, are installed to support the overall design.

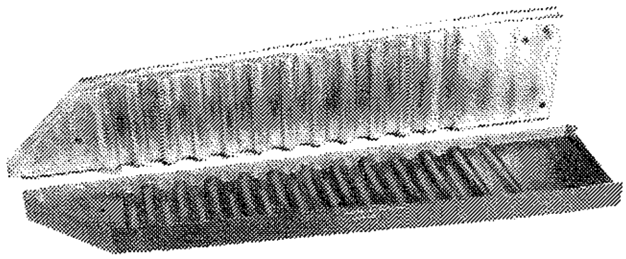

Fig. 9 : SINE WAVE CRASH STRUCTURE

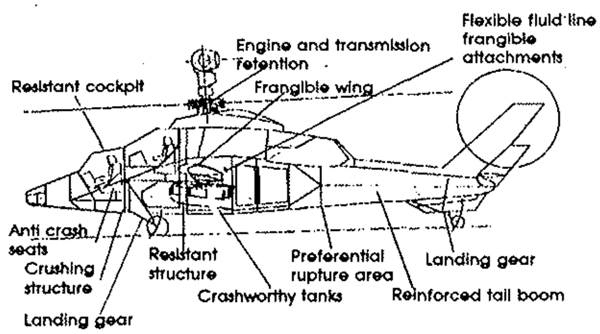

Fig. 10 : CRASH PROTECTION SYSTEM

3. Main Rotor

3.1 Design

The Tiger main rotor has been designed with the following criteria :

- low weight
- excellent manoeuvrability
- low number of parts
- minimal maintenance
- simplicity and ruggedness
- low vulnerability
- high service life

Fibre composites were used to achieve these ambitious objectives.

Standard parts excepted, the full rotor structure includes a few main components only.

The layout of the Tiger rotor system is essentially determined by the hingeless, soft inplane rotor concept proved with an experimental rotor (URF). The flap and lead lag motions are allowed by elastic bending of the neck region. The elastomeric bearings authorize torsional (pitch) motions. The centrifugal force is transmitted to the hub by the conical bearing.

All components other than bearings are designed to have an infinite life.

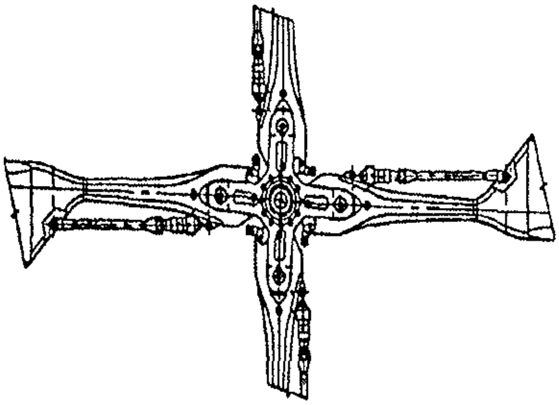

Fig. 11 : MAIN ROTOR

3.2 Manufacture

All composite parts are manufactured with prepreg materials to mechanize production. Special attention was given to the manufacturing process of very thick components such as attachment areas of the blade or hub plates to avoid any hot spot occurrence. This effect is likely in case of excessive material build ups because of the exothermal reactions of epoxy resins.

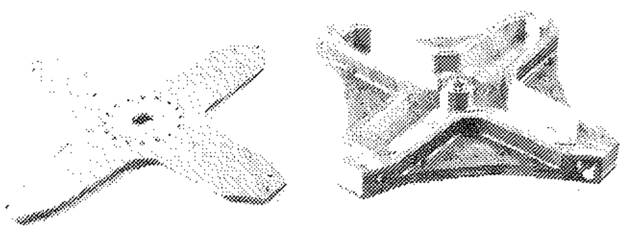

Fig. 12 : HUB PLATES MANUFACTURING TOOL

The tooling concept, the manufacturing and the curing processes were carefully harmonized. Several special parts have been produced and tested to prove the selected concept.

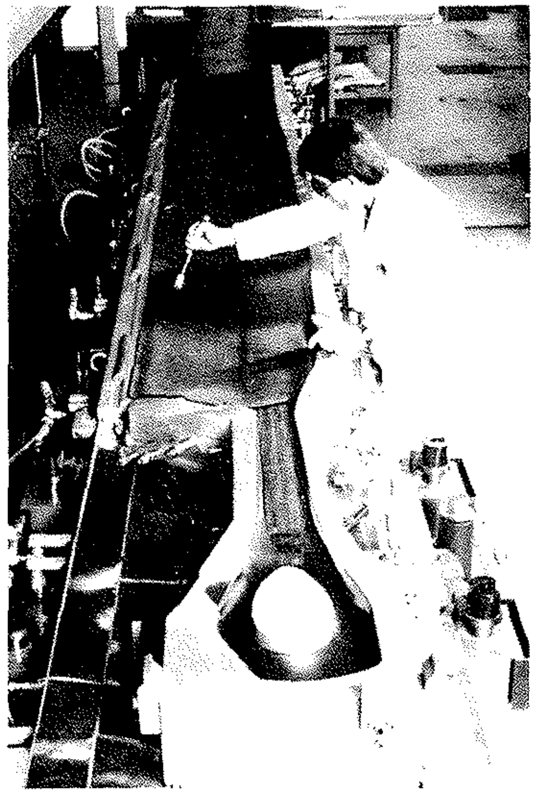

Fig. 13 : MAIN BLADE MANUFACTURING TOOL

3.3 Tests

All main components of the main rotor system such as hub structure, elastomeric bearings, lead lag damper, blade root, aerodynamic section and blade tip has been fatigue tested with special test rigs. The hub structure test rig is shown as an example. With this test apparatus it is possible to apply rotary dynamic loads such as centrifugal forces, inplane and flap bending moments on the 4 rotor arms.

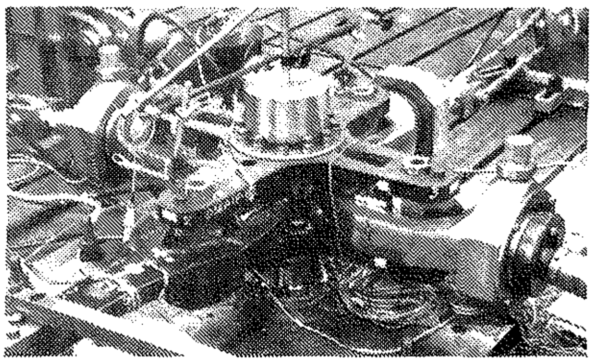

Fig. 14 : HUB STRUCTURE FATIGUE TEST BENCH

In addition to the component tests, system tests with main rotor are performed on the whirl tower.
Special tests will be conducted on the Iron Bird early in November 90 in combination with every other drive system component.

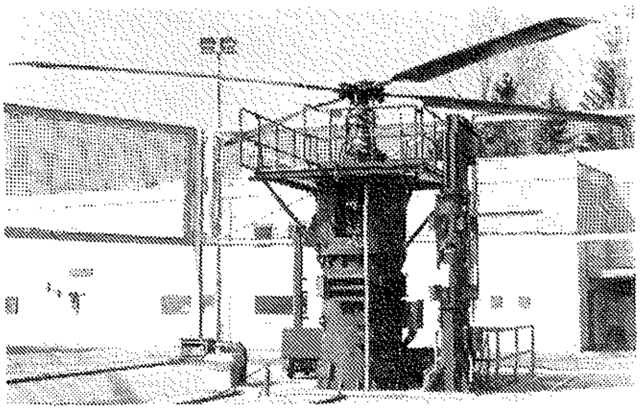

Fig. 15 : MAIN ROTOR IN WHIRL TOWER

4. Tail Rotor

4.1 Design

The tail rotor has been designed and sized to give the helicopter an excellent yaw manoeuvrability.

The 3-blade, Spheriflex type rotor has been selected because it was the best compromise between weight, performance, costs and maintenance factors.

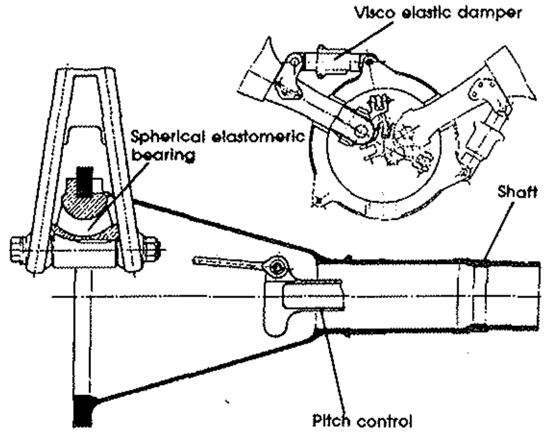

Fig. 16 : TAIL ROTOR

Since this rotor is of the «soft-in-plane» type, it became necessary to dampen blade movement in drag to avoid a first drag mode/structure mode coupling and this was done with visco-elastic dampers.

The hub and the shaft have been made into a single titanium part to reduce the number of parts therefore, increasing reliability and, subsequently, reducing weight. Laminated spherical thrust bearings are inserted between this part and the blade roots.

The tail rotor blade has been designed for optimum performance and noise reduction. It is equipped with a modern, high aerodynamic performance airfoil. It is twisted over its full length and thickness as well as chord tapered at he tip (parabolic leading edge).

This blade is made of high performance composite materials which structure is particularly damage tolerant.

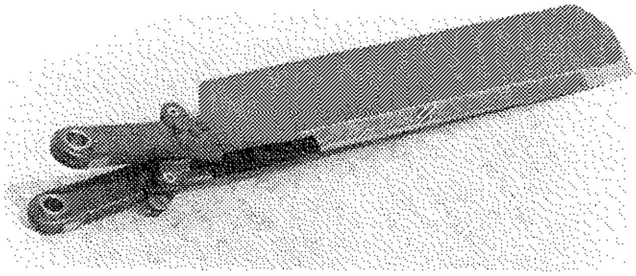

Fig. 17 : TAIL ROTOR BLADE

This blade's mode original feature is the fork shape of its attachment which helped simplify the hub's design.

4.2 Manufacture and Tests

Designing this fork with composite materials may have generated technical problems and high manufacturing costs but a solution was found and it was demonstrated on the very similar AS 332 MK II blade first and the TIGER blade afterwards that this fork could be moulded in a single operation without significant cost increases.

Preliminary fatigue resistance tests were undertaken with blade sections, elastomeric spherical thrust bearings and visco-elastic dampers. The results are to date highly satisfactory.

Two full rotors i.e. with hub and blades have been manufactured and assembled.

The first rotor was tested in the balance rig which main function, as its name implies, is to measure performance accurately. Thrust and power consumed as a function of pitch measurements were made and the results were strictly in compliance with calculations.

The balance rig also helped testing the rotor's dynamic behaviour thanks to a transverse dynamic excitation.

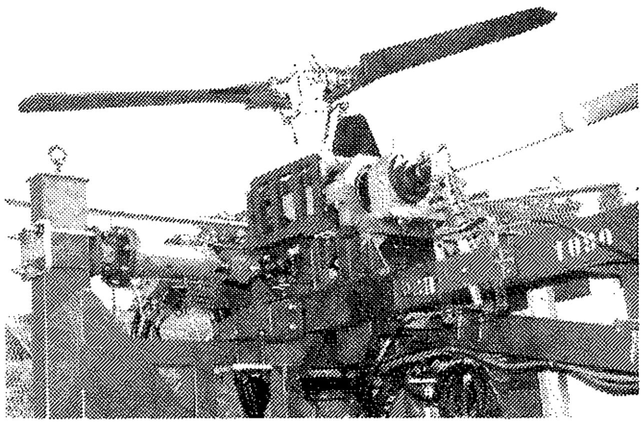

Fig. 18 : TAIL ROTOR IN BALANCE RIG

An overspeed test at 115 % of the nominal rating was also undertaken in the balance rig.

The tail rotor is now in the Iron Bird and tests are to proceed from Nov. 1st, 1990.

5. Main Gear Box

5.1 Design

Considering the helicopter's narrowness and the need to reduce the weight, optimizing the MGB meant selecting an architecture with 3 reduction stages where :

- the first stage is composed of spiro-bevel gears and includes the free wheels
- the second stage is a mixing stage com - posed of cylindrical, helicoidal gears
- the output stage to the main rotor is epicyclic

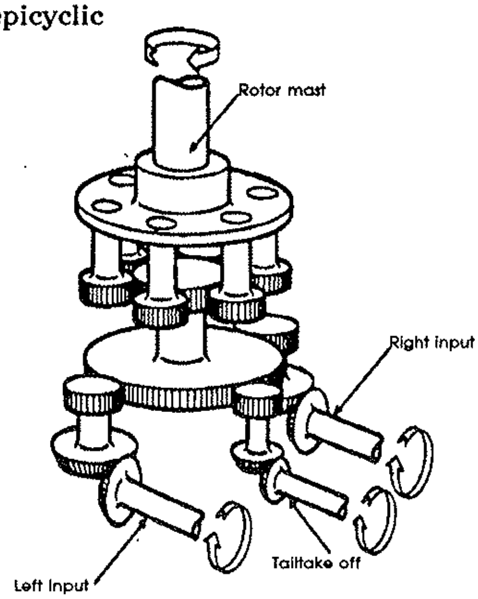

Fig. 19 : MGB ARCHITECTURE

The MGB will be highly reliable and safe thanks to the following technical options :

- Bolt and spline assemblies were avoided
- Some gears and shafts are electronic beam welded
- Inner bearing tracks are mostly integral with shafts to avoid inner bushes and their attachments
- Gear teeth and inner bearing tracks are hardened by deep nitriding prior to grinding
- Bearings are made of M50 steel
- The two lubrication systems are segregated
- The lubrication ducts are integral with casings
- The different modules are lubricated separately and particle detection is provided in each module
- Finally, the MGB was designed in such a way to continue flying for 30 minutes after complete oil loss.

5.2 Manufacture and Tests

The following tests were undertaken before the full MGB became available :

- Deformation under load of an MGB casing made of resin. The results of this test were introduced in the spiro-bevel gear teeth pattern's prediction programme and helped undertake a preliminary optimization of gear teeth grinding
- Bearing operation without oil for operating profile and play selection
- Lubrication optimization with oil jets visualization
- Oils pump's preliminary operation and endurance

Two full MGBs have so far been manufactured and run in the back-to-back rig which, as mechanical engineers are fully aware, is a closed loop rig helping simulate transmission of a high power with minimum rig driving energy consumption.

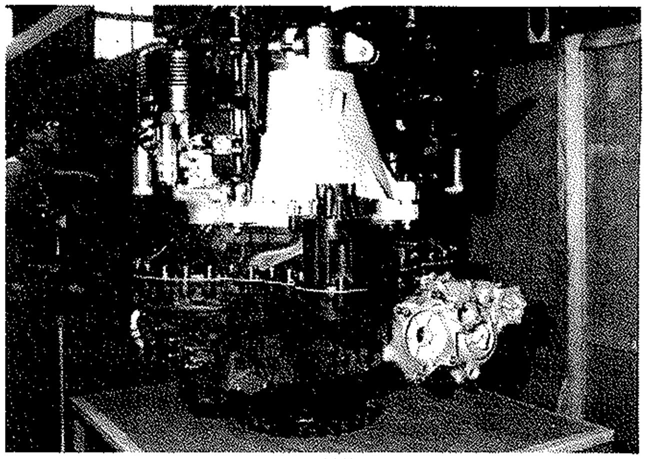

Fig. 20 : FULLY EQUIPPED MGB

This rig includes hydraulic torquing devices and allows applying lift loads as well as the mast moments at the MGB output.

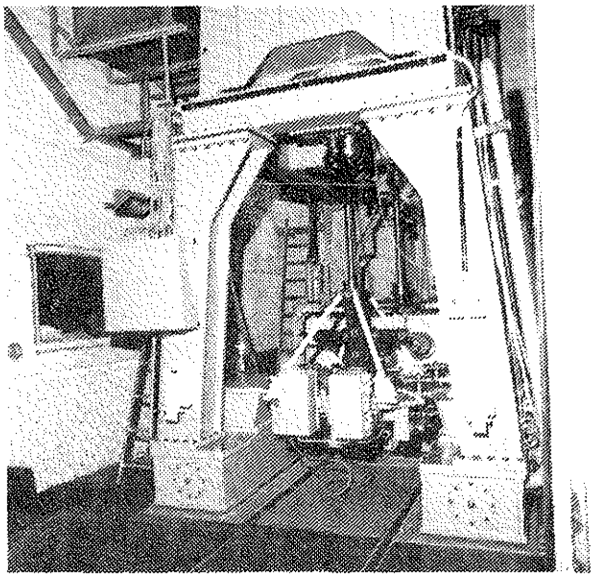

Fig. 21 : BACK-TO-BACK RIG

Both MGBs have been subjected to operating checks and preliminary adjustments in this rig, including :

- Temperature measurements
- Jet delivery optimization
- Gear teeth pattern check

The results being satisfactory, one of these MGBs has been transferred to the Iron Bird while the second remained on the back-to-back rig to continue development tests. The objective is to have, early in 1991, gear teeth patterns transmitting maximum power in sufficient reliability conditions for the preliminary endurance test on the Iron Bird and the first prototype's flight.

6. Tail Rotor Drive

6.1 Design

The need to optimize the tail rotor drive shaft from weight, resistance, reliability, maintenance and vulnerability criteria led us to retain the following solution :

- The horizontal shaft between the main and the intermediate gear box is composed of two super-critical metal sections. Damping as the critical rating is reached on the ground is undertaken by a simple and reliable device i.e. a plain bearing connected to the structure by a friction system.

- The oblique shaft between the intermediate and the tail gear box is composed of a single, sub-critical carbon fibre/epoxy resin section.

The tail rotor drive shaft's weak points usually are the bearings and it can be noted that there remains on the whole drive shaft only one bearing, a significant advantage as far as reliability, safety and vulnerability is concerned.

6.2 Manufacture and Tests

The first tail rotor drive shafts as well as the intermediate and tail gear box have been manufactured for Iron Bird tests and the first prototype.

The composite oblique shaft is the result of the technological research work undertaken over the last few years. This shaft has been successfully subjected to numerous static and fatigue resistance tests performed both on the shaft itself and its connections with the end flanges.
The first firing tests have also been undertaken with 30 and 50 (7.62 and 12.7 mm) calibre weapons ; these tests demonstrated a satisfactory residual resistance of the composite shaft and confirmed the, initially intuitive, principle that the resistance to the highest weapon calibre calls for a larger diameter shaft.

7. Sarib Suspension

7.1 Design

The French SARIB acronym stands for Suspension Anti-Résonante Intégrée à Barres which can be translated by Integrated Anti-Resonance Suspension with Struts.

This suspension strongly reduces the transmission of vibrations generated by the main rotor to the structure.

It is composed of four flapping masses associated to four flexible blades and four struts ; the hinges are laminated elastomeric bearings.

The torque is transmitted from the MGB to the transmission deck via a membrane rigid in torsion but deformable upon bending.

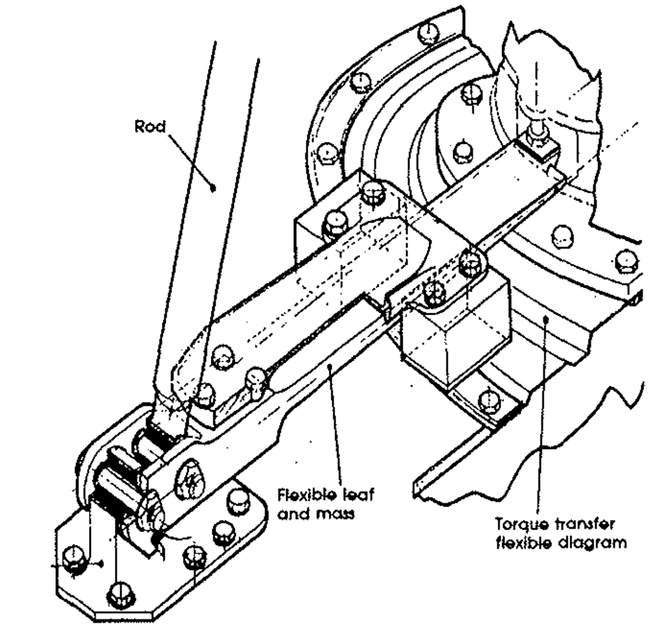

Fig. 22 : MGB "SARIB" SUSPENSION

7.2 Manufacture and Tests

The SARIB concept was developed under a research programme, experimented in the laboratory and in an Ecureuil helicopter in flight where results were excellent.
3 copies of the Tiger SARIB have been manufactured : One for Iron Bird tests, one for the first prototype and one currently undergoing laboratory tests intended to validate the mathematical model and refine the mass/stiffness setting determined by calculation.

8. Flight Controls Hydraulic System

8.1 Design

The flight controls, fully identical for pilot and copilot/gunner, are of the mechanical type. They are supported by a redundant duplex AFCS with stabilization and AP-functions, as shown in the drawing below.

They consist of mechanical controls identical for the Pilot and Gunner (cyclic, yaw, collective), a mechanical collective/yax mixing unit, a hydraulic preamplification, a trim system for all axes, the dual main rotor actuators and the dual tail rotor actuator.

The hydraulic system, necessary to supply the actuators of the flight control system consists of two independent but identical main power systems mechanically driven by the main gear box and an auxiliary hydraulic power train electrically driven to be used when the main rotor is not running (preflight checks, maintenance actions).

One of the main power supplies is connected, in addition, to the rotor -and wheel brake-systems as well as to the auxiliary hydraulic system.

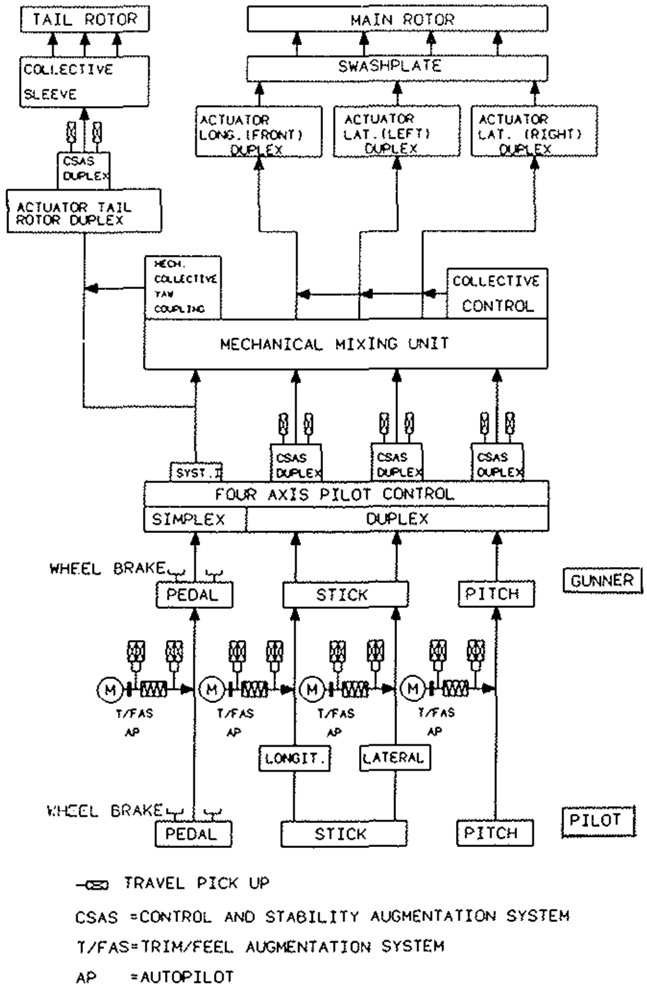

Fig. 23 : FLIGHT CONTROLS SCHEMATICS

8.2 Manufacture and tests

Supplier items such as the actuators and the hydraulic power units are manufactured and tested at the suppliers. The components of the upper control system such as the swashplates, scissors and rotating control rods are manufactured and tested at MBB.

Specific test equipement was used to perform these tests.

Most important for the quality of the flight control system is the knowledge af the combined functions of all hydraulic and mechanical components. To achieve predictive results prior to the 1st. flight, a special test rig was built which allows simulating the reaction forces of the main and tail rotor.

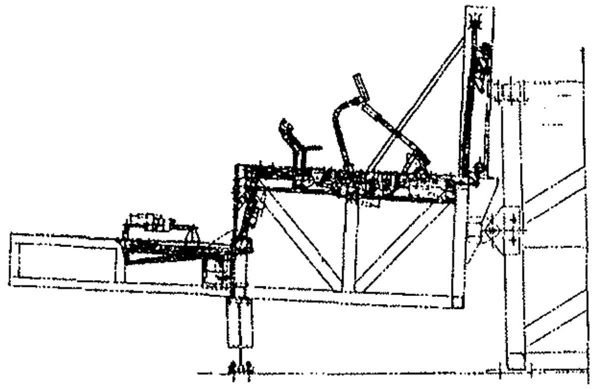

Fig. 24 : FLIGHT CONTROLS AND HYDRAULIC TEST RIG

This test rig is designed for connection with the IRON BIRD, thus giving the ability to perform further realistic tests of the complete flight control and hydraulic system.

9. Engine and Engine Installation

9.1 Engine

The MTR 390 engine is being developed under a separate contract signed at the end of 1989 between the bilateral Authorities and the MTR consortium composed of MTU, Turbomeca and Rolls-Royce.

MTR 390 is an advanced modular engine equipped with an integral oil and cooling system and a Full Authority Digital Electronic Control (FADEC).

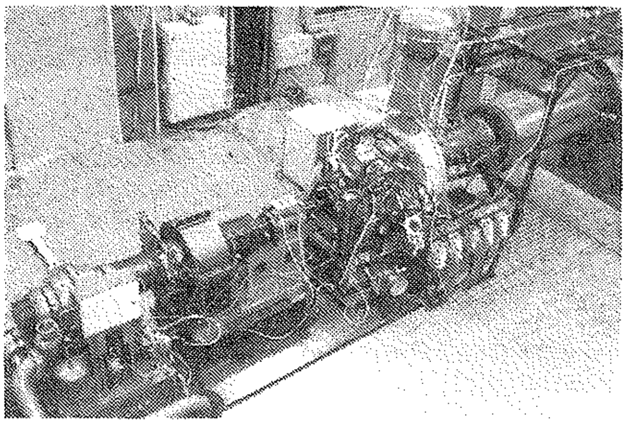

Fig. 25 : MTR 390 ENGINE ON BENCH

The engines have now run more than 150 hours on the rig as of July 1990 with power phases of more than 1000 kW.

The available power and specific consumption performances measured are in compliance with predictions and in agreement with the contractual values specified for the prototype engines.

Two engines have been adapted on an AS 365 Dauphin helicopter acting as a «rig» that is to fly in October 1990.

9.2 Engine installation

This includes engine control and monitoring, mechanical supports, fire walls, fuel system, fire extinguishing circuit as well as upper cowlings integrating air intakes and hot gas exhausts.

- The air intakes are of the semi static type with protecting grids and can be equipped, according to mission, with a Vortex particle separator
- The gas outputs are equipped with an I.R. suppressor
- Air intakes and exhausts have already been subjected to half scale wind tunnel tests intended to measure drag, pressure losses (air intakes) and dilution (IR suppressors).
- The very simple and compact fuel system has been designed for maximum survivability, crash resistance and self-sealing

A fuel system rig has been made in a central structure element representative of the helicopter.
This rig is operational to undertake static and dynamic tests.

10. IRON BIRD

A universal modular test bench called Iron Bird has been built to undertake dynamic assemblies tests in high loading conditions and in a representative configuration.

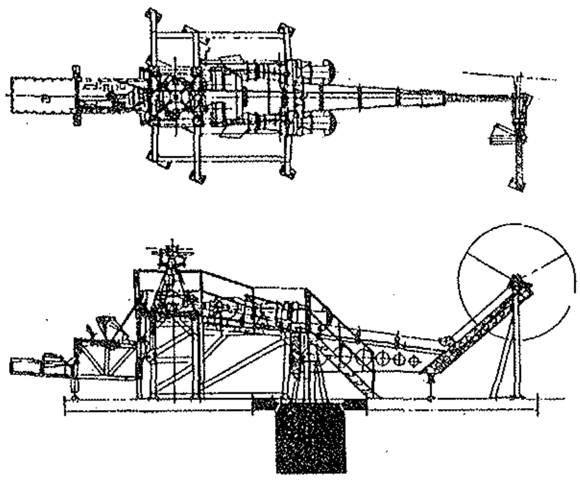

Fig. 26 : IRON BIRD

Two Turbomeca TURMO III C4 engines are installed to perform high power tests from the beginning i.e. before PTI first flight.

11. First Prototype Situation

Manufacture of the PT1 mechanical components is nearly complete, only some secondary parts remain to be completed. Assembly procedure of the main and secondary parts is in progress and will be finished on schedule. The necessary tests for components and systems prior to first flight can all be finished to meet the proposed time schedule, although some problems occurred because of late component delivery by the suppliers. The 1st. flight date should thus be met. All results of tests performed to date have been satisfactory, in accordance with the expected values.

CONCLUSION

International cooperation is enriching in that a synergy is generated provided most of the partners' energy is not wasted confronting concepts or promoting one's own technological solutions and working methods.

On the contrary, it is preferable to seek compromises, synthetize and finally draw the best out of each partner.

This is what we have attempted to do throughout the course of the Tiger programme and we believe we can rapidly demonstrate that our cooperation has been successful.
It has been shown that Tiger development is today very much a reality ; the components and sub-systems have been manufactured and tests are now well advanced.

Dynamic assemblies' tests will start from November 1990 in the Iron Bird and the first prototype should fly in April 91 as planned.